

AD-A237 963



main

2

Discriminability, Loudness, and Masking in the Rat (*Rattus norvegicus*): A Confirmation and Extension

Thomas G. Raslear

Department of Medical Neurosciences

Walter Reed Army Institute of Research, Washington, D. C.

Acquisition For
DTIC Tab
Unannounced
Justification

By
Distribution

Availability Codes

Dist Avail and/or
Special

A-1 20



In Experiment 1, rats discriminated between two sound pressure levels (SPL) of a pure tone: standard (STD) SPLs of 84 and 74 dB and comparison (CO) SPLs 4, 14, and 24 dB below STD were tested in quiet and 60 dB noise at 4 and 12.5 kHz (24 conditions). The decibel difference between STD and CO accounted for only 43.52% of the variance in the signal detection measure of sensitivity, d' , across conditions, whereas the loudness difference ($LD = STD^{0.35} - CO^{0.35}$) accounted for 89.82% of the variance in d' . These results confirm and extend previous observations that: (a) equal decibel differences are not equally discriminable; (b) loudness for the rat increases as a power function of SPL with an exponent of 0.35; and (c) masked loudness is a linear function of loudness in quiet. In Experiment 2, the assumptions of normal distribution and equal variance implicit in the use of the d' measure were examined. Receiver operating characteristic curves that were well approximated by straight lines of unit slope in normal-normal coordinates were obtained and thereby validated the use of d' in Experiment 1.

A method by which discrimination data can be used to derive a loudness scale for animal subjects (Pierrel-Sorrentino & Raslear, 1980; Raslear, Pierrel-Sorrentino, & Rudnick, 1983) has recently been described. The derivation of a loudness scale from discrimination data depends on two assumptions: (a) In the discrimination task, perceived differences between stimuli are judged, and (b) equivalent discriminative performances indicate equal loudness differences between stimulus pairs. Thus, if a discrimination between a first intensity (I_1) and a second intensity (I_2) is equivalent to that between I_3 and I_4 , then

$$L_1 - L_2 = L_3 - L_4, \quad (1)$$

where L_i is the loudness of I_i , and so forth. Empirically obtained discriminative matches are consistent with a generalization of Stevens's power law (Lochner & Burger, 1961),

$$L = k(I^n - I_0^n), \quad (2)$$

where k , I_0 , and n are constants, because

$$I_1^n - I_2^n = I_3^n - I_4^n, \quad (3)$$

where $n = 0.35$ for the rat and $n = 0.25$ for the chinchilla.

In Equation 2, I_0 is the absolute threshold in quiet or the masked threshold in noise. Under masking conditions the

value of k and I_0 would change, but n would remain constant. From this it follows that masked loudness is a linear function of loudness in quiet (see Raslear et al., 1983):

$$L_m = \kappa L_q - b, \quad (4)$$

where κ and b are constants.

Lochner and Burger (1961) found that Equation 2 provided a good description of their data for quiet and for four levels of noise masking, and Raslear et al. (1983) found that Equation 2 provided a good fit to the masking data of Hellman and Zwillocki (1964) and to their own data on masked, auditory-intensity discrimination in rats.

The method of measuring discriminability in the Pierrel-Sorrentino and Raslear (1980) and Raslear et al. (1983) studies, however, may be flawed. Both studies used a free-operant successive discrimination procedure in which rates of responding were used to determine the relative control over responding exerted by differences in the sound levels presented to the animals (see Raslear, Pierrel-Sorrentino, & Brisse, 1975). A discrimination index is derived from response rates to quantify the dependency of response rate on stimulus level, but it is not clear that such a measure is a bias-free index of sensitivity in the sense of signal detection theory (Green & Swets, 1966). If their discrimination index is biased, the conclusion that Equation 3 is satisfied may be incorrect.

The two experiments described in this article explore the relationship between discriminability and loudness by using behavioral methods that allow the use of the signal detection index of sensitivity, d' . Our assumptions about discriminability and the definition of d' imply that

$$d' = (L_1 - L_2) / \sigma, \quad (5)$$

where σ is the standard deviation of the loudness percept.

Rather than obtain discriminative matches (i.e., finding pairs of stimuli that yield equivalent values of d') as had been

The research described in this article was conducted in compliance with the Animal Welfare Act and other Federal statutes and regulations that relate to animals and experiments involving animals and adheres to the principles stated in the *Guide for the Care and Use of Laboratory Animals* (1985). The views of the author do not purport to reflect the position of the Department of the Army or of the Department of Defense.

Correspondence concerning this article should be addressed to Thomas G. Raslear, Department of Medical Neurosciences, Walter Reed Army Institute of Research, Washington, D. C. 20307-5100.

91-04071

done in previous research, the first experiment obtained d' estimates for a wide range of stimulus pairs in quiet and noise at two frequencies. On the basis of previous results, it was predicted that:

1. In quiet, d' would be directly proportional to loudness differences between stimulus pairs, when $n = 0.35$. This prediction follows directly from Equation 5.

2. The d' values for the same stimuli in quiet (d'_q) ought to be directly proportional to those in noise (d'_m). This follows from Equations 4 and 5. From Equation 4, in masking the loudness difference between two stimuli is:

$$L_{m1} - L_{m2} = \kappa(I_{q1} - I_{q2}). \quad (6)$$

From equation 5 and 6 it follows that

$$d'_m = \kappa d'_q. \quad (7)$$

3. In noise, d' ought also to be proportional to the loudness differences between stimulus pairs. Loudness differences in this case are calculated from Equation 6 with κ equal to the constant of proportionality between d'_q and d'_m .

The second experiment varied payoffs for selected stimulus pairs presented in quiet and in noise so that receiver operating characteristic (ROC) curves could be plotted to evaluate the suitability of using the d' measure as a point estimate of sensitivity. Because loudness differences are assumed to be proportional to d' (see Equation 5), it is important to check the assumptions that underlie the use of d' . If the assumptions of equal variance, normal distributions for loudness percepts are not valid, then the use of d' measures in Experiment 1 could lead to false conclusions about changes in sensitivity (Egan, 1975; Green & Swets, 1966) and, ultimately, about loudness perception in the rat.

Experiment 1

Method

Subjects

Three male, albino Sprague-Dawley rats from the Walter Reed Army Institute of Research colony served as subjects. The animals were approximately 90 days old at the beginning of the experiment. The rats were reduced to approximately 80% of their free-feeding body weight by restricted feeding. Water was available at all times in individual home cages.

Apparatus

The test cage was a 23 cm wide \times 23 cm high \times 26 cm deep enclosure constructed of hardware cloth. A pan with paper towels for animal waste was located 25.5 cm below the cage floor. Two response levers were mounted on one wall of the cage, 13 cm apart and 4 cm above the floor. The opposite wall contained a food magazine and water bottle spout. A tube delivered 45-mg food pellets (Bio-Serv, Frenchtown, New Jersey) to the food magazine from a pellet dispenser located in a far corner of the chamber that contained the test cage.

The test cage was located inside an anechoic chamber (Eckel Industries, Cambridge, Massachusetts, Model 545-250-2) with a free-field volume of 1.02 m³. The ambient sound pressure level (SPL) in the chamber was 9.02 dB (linear scale), as measured with a Bruel and Kjaer measuring amplifier (Model 2606), microphone preamplifier

(Model 2619), band-pass filter (Model 1618), and a 1-in. condenser microphone (Model 4145). The calibration of the sound level measurement system was periodically checked with a Bruel and Kjaer pistonphone (Model 4220). The piezoelectric tweeter (Motorola, Model KSN6005A) that was used to deliver pure tones was centered 26 cm above the test cage. A second piezoelectric tweeter, used to deliver noise, was located on the far wall of the chamber, 34 cm above the test cage.

Two Hewlett-Packard frequency synthesizers (Model 3325A) were used to generate pure tone stimuli, and noise was produced by a Coulbourn (Model S81-02) noise generator. Relative to a 100-dB tone measured at a point in the center of the test cage at the level of a rat's head (6.5 cm), the sound field, sampled at 12 positions with a Bruel and Kjaer 1/4-in. condenser microphone (Model 4136) attached to the sound measurement system, had a standard deviation of 1.67 dB at 4 kHz and 2.38 dB at 12.5 kHz. Tonal and noise stimuli were gated (Coulbourn Model S84-04) with rise-decay times of 50 ms.

Procedure

General. Experimental sessions for each subject occurred at approximately the same time each day, 5 days per week excluding holidays. Subjects were weighed after sessions to determine the amount of supplemental food they would receive following the session. Figure 1 presents the general structure of a trial.

Initial discrimination training. A two-choice, discrete-trials paradigm was used in which the animals were trained to discriminate between the 84-dB, 4-kHz standard and the 60-dB, 4-kHz comparison stimuli. Noise was not presented during training. Responses were effective only in the 5 s after the discriminative stimulus. Responses during the first 7 s of a trial were ineffective. Correct responses (i.e., a response on the standard lever given the standard stimulus or a response on the comparison lever given the comparison stimulus) terminated the trial and produced a 45-mg food pellet. Incorrect responses terminated the trial and caused the stimulus to be presented again after 20 ms (correction procedure). If no response was made within 5 s, the trial terminated, a null response to that stimulus was recorded, and the correction procedure was again initiated. The intertrial interval was 5 s, during which time responses had no effect. In the absence of incorrect responses, the standard and comparison stimuli were equally likely to occur on a trial. Training was continued until each rat performed the task with 80% accuracy over a period of 5 consecutive days.

Testing. After initial discrimination training the rats were twice exposed to the 24 stimulus conditions, one per day in random order. Table 1 presents the conditions that were used in Experiment 1.

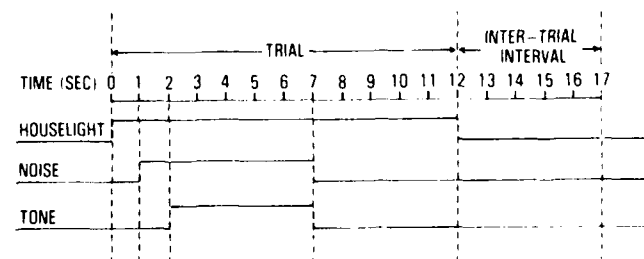


Figure 1. The structure of a trial. (Each trial begins with the onset of the house light. One s later, noise onset occurs, if noise is to be presented on that trial. One s later, tone onset occurs. Tone and noise are terminated 7 s from the beginning of the trial. The house light remains on for an additional 5 s to indicate the choice period. The choice period is followed by a 5 s intertrial interval.)

Comparison intensities at 4, 14, and 24 dB below the standard intensity were presented at each of two frequencies (4 and 12.5 kHz), two standard intensities (84 and 74 dB), and two noise levels (0 and 60 dB[A]).

The correction procedure was not used during testing. A response on the correct lever during the 5-s response period terminated the trial and produced a food pellet. An incorrect response merely terminated the trial. Rats received 300 trials per day; the first 20 trials were used as a warm-up and were not used in data analyses.

Data analyses. Hits were defined as responses on the standard lever after the presentation of the standard stimulus, false alarms were defined as responses to the standard lever after the presentation of the comparison stimulus, correct rejections were defined as responses on the comparison lever after the presentation of the comparison stimulus, and misses were defined as responses on the comparison lever after the presentation of the standard stimulus. Hits, false alarms, correct rejections, and misses were pooled across replications of conditions for each rat. From the pooled data the probabilities of hits and false alarms and of d' were determined for each condition for each rat, and these values were used to calculate the means for each condition. The probability of a hit, $p(\text{HIT})$, was defined as the number of hits divided by the total number of trials on which the standard was presented and a response was made (i.e., trials on which no response was made were not counted), and the probability of a false alarm, $p(\text{FA})$, was defined as the number of false alarms for the comparison stimulus divided by the total number of trials on which that stimulus was presented and a response was made. Values of d' were computed by converting $p(\text{HIT})$ and $p(\text{FA})$ to z scores (Green & Swets, 1966) and performing the operation $z(\text{HIT}) - z(\text{FA})$. Statistical and mathematical analyses were conducted with the SAS (SAS Institute, 1985) statistical package.

Results and Discussion

Figure 2 presents the mean d' values for each of the 24 conditions as a function of the decibel difference between the

Table 1
Stimulus Conditions for Experiment 1

Frequency (in kilohertz)	Standard (in decibels)	Comparison (in decibels)	Noise (in decibels)
4	84	80	0
4	84	70	0
4	84	60	0
4	74	70	0
4	74	60	0
4	74	50	0
4	84	80	60
4	84	70	60
4	84	60	60
4	74	70	60
4	74	60	60
4	74	50	60
12.5	84	80	0
12.5	84	70	0
12.5	84	60	0
12.5	74	70	0
12.5	74	60	0
12.5	74	50	0
12.5	84	80	60
12.5	84	70	60
12.5	84	60	60
12.5	74	70	60
12.5	74	60	60
12.5	74	50	60

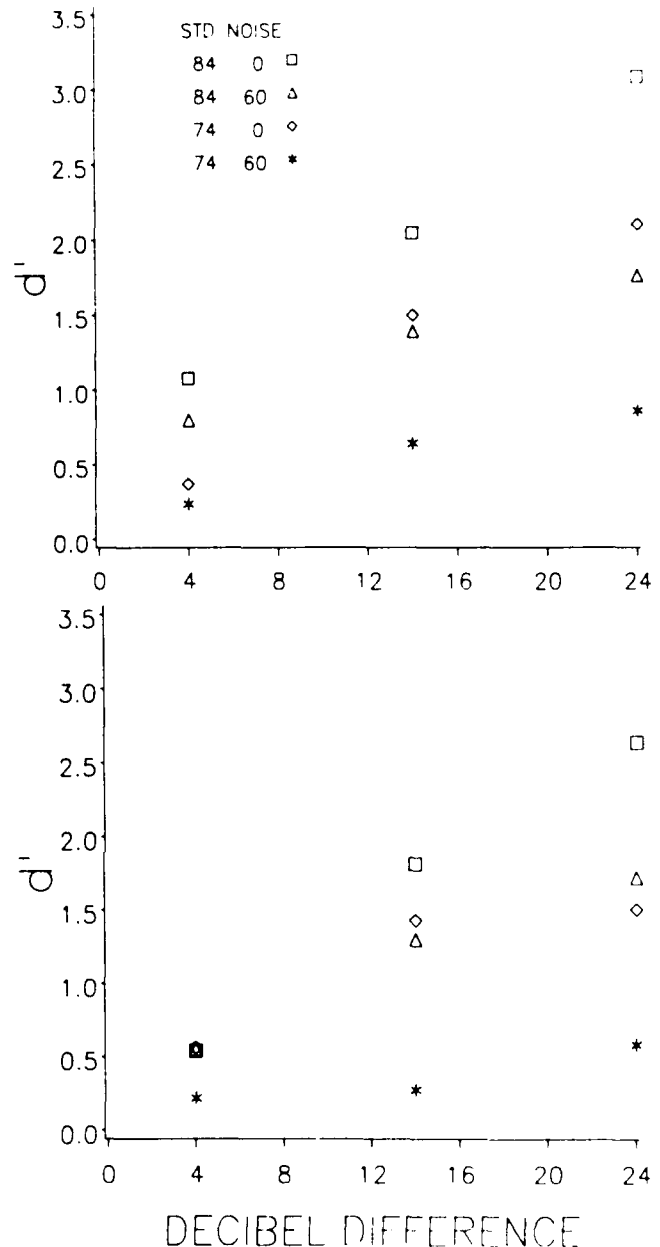


Figure 2. Mean d' values as a function of the decibel difference between standard and comparison stimuli for all conditions in Experiment 1. (The top and bottom panels present data from the 4 and 12.5 kHz conditions, respectively.)

standard and comparison tones. In general, d' values are lower in noise than in quiet and are lower for equivalent dB differences at 12.5 kHz than at 4 kHz.

Equal decibel differences clearly do not produce equal discriminative performances, as can be seen by comparing d' values for 84- and 74-dB standards at the same dB difference within a frequency. This lack of conformity with Fechner's law is well known in the human literature (Parker & Schneider, 1980) and has been previously noted by Pierrel, Sherman, Blue, and Hegge (1970) for rats' discrimination of 4-kHz

tones in quiet. These results extend that observation to another frequency and masking noise. A regression analysis of d' values as a function of the decibel difference between standard and comparison tones was performed to quantify the relationship between d' and dB difference. Although a reliable linear relationship was found, $F(1, 22) = 16.95$, $p = .0005$, the dB difference between standard and comparison stimuli only accounts for 43.52% of the variance in d' .

Equation 7 predicts that d' values in quiet and noise ought to be directly proportional; that is, in a regression analysis, there ought to be a reliable slope and a zero intercept. Figure 3 shows the relationship between d' values in noise (d'_n) and in quiet (d'_q) for the same stimuli. The straight line is a least squares fit, $F(1, 10) = 25.52$, $p = .0005$, $r^2 = .7185$ with zero intercept and slope of 0.579. It is clear that Figure 3 is consistent with Equation 7 and satisfies the prediction of proportionality between d' values in noise and quiet.

Figure 4 presents the mean d' values of Figure 2 as a function of the loudness difference between the standard and comparison tones. For the quiet conditions the loudness difference was simply $I_1'' - I_2''$, $n = 0.35$. For the noise conditions, the loudness difference was $0.579(I_1'' - I_2'')$, $n = 0.35$. A regression analysis of the loudness difference data accounted for 89.82% of the variance in d' , $F(1, 22) = 194.05$, $p = .0001$. The slope of the best fitting line was 0.05 with a zero intercept, as required by the prediction that d' in quiet and noise is proportional to the loudness difference between tones.

The results presented in Figure 4 strongly support and extend previous work by Raslear et al. (1983) and Pierrel-Sorrentino and Raslear (1980). They determined that the

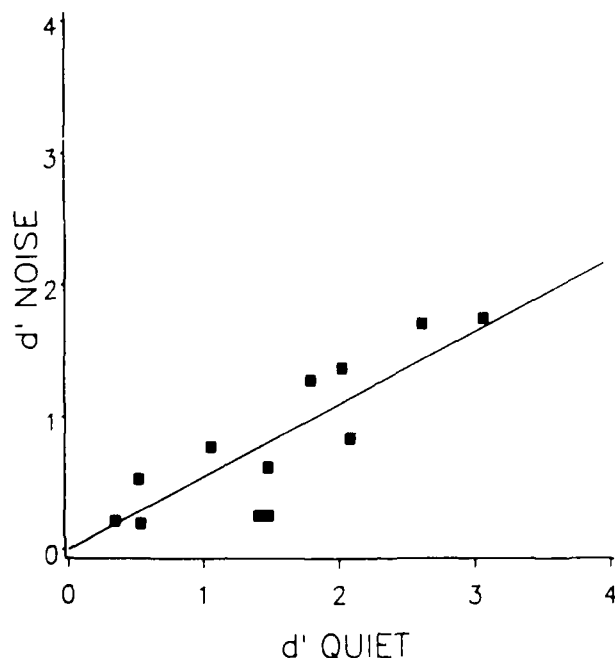


Figure 3. Mean d' values in 60 dB noise plotted as a function of the d' value obtained for the same standard and comparison stimuli in quiet. (The straight line is the regression line.)

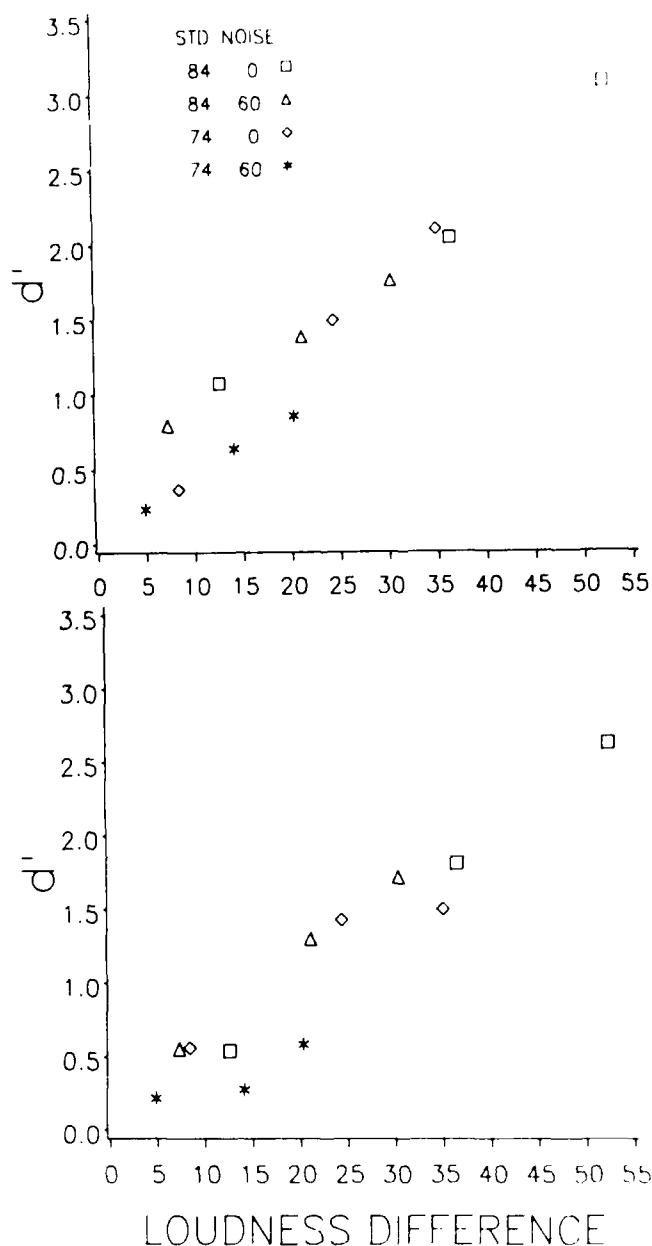


Figure 4. Mean d' values as a function of the loudness difference between standard and comparison stimuli for all conditions in Experiment 1. (The top and bottom panels present data from the 4 and 12.5 kHz conditions, respectively.)

exponent of Stevens's power law was 0.35 for the rat by finding pairs of stimuli that produced the same discriminative performances so that Equation 3 could be solved. My experiment used that previously determined value of n to calculate loudness differences for the stimuli in use. It is surprising that so good a fit was obtained to data that were generated in a different lab with different procedures than those with which n was originally estimated. It is even more surprising that the estimate of n does well for a different frequency.

The main concern in performing this experiment was that the procedures previously used by Raslear et al. (1983) and

Pierrel-Sorrentino and Raslear (1980) might contain undetected sources of bias that could influence their estimate of n . Unlike the previously used procedures, my experiment used a two-choice, discrete-trials procedure so that a signal detection analysis measure of discriminability, d' , could be used. Whereas the data of Experiment 1 strongly suggest that valid estimates of n were obtained, note that point estimates of d' are also subject to alternative interpretations (Egan, 1975; Green & Swets, 1966). The method of calculating d' rests on the assumption that the underlying distributions of sensory events are equal variance normal. If these assumptions are false, sensitivity (discriminability) is not properly indexed by changes in d' (i.e., d' changes even though sensitivity did not). Because our conclusions in Experiment 1 rest on the observed changes in d' , it is essential that the equal-variance, normal-distribution assumption be tested. This was the purpose of Experiment 2.

Experiment 2

A method for determining the appropriateness of distributional assumptions in signal detection experiments is through the analysis of ROC curves (Egan, 1975). ROC curves are isosensitivity functions: They plot changes in $p(\text{HIT})$ versus $p(\text{FA})$ for fixed stimulus conditions as variables that influence the subject's criterion (bias) are varied. Because the stimuli do not change, sensitivity is the same at all points. ROC analysis consists of plotting several ROC curves in coordinates that are consistent with putative underlying distributions of sensory events. Expected ROC configurations are then compared with the obtained ROCs. For instance, if it is assumed that equal-variance normal distributions underlie loudness judgments, then normal-normal coordinates are used to plot $p(\text{HIT})$ versus $p(\text{FA})$, or equivalent, $z(\text{HIT})$ versus $z(\text{FA})$ plots. ROCs with the expected underlying distributional characteristics plot as straight lines with unit slope. Systematic deviations from that pattern are diagnostic of other distributional assumptions, which can be similarly tested. As an example, Raleigh distributions are implied if ROCs plotted in normal-normal coordinates all tend to converge in the upper right-hand corner of the plot (Egan, 1975).

ROCs were generated in Experiment 2 by simply varying the payoffs (i.e., the probability of a food pellet for hits and correct rejections) of Experiment 1. The expected effect of variations in payoffs is to induce a response bias. This was done for three stimulus pairs, in quiet and noise, with five distinct payoff matrices to test the equal variance normal distribution assumption.

Method

Subjects and apparatus

Same as used in Experiment 1.

Procedure

Trials were structured and scheduled as before. However, in order to vary the response criterion (bias), the probability of receiving a

food pellet for a correct response after each stimulus was systematically varied. Table 2 presents the conditions used in Experiment 2. Each condition was presented in the order indicated. All tonal stimuli were 4 kHz. For each condition the hits, false alarms, correct rejections, and misses were summed across subjects to determine group values of $p(\text{HIT})$ and $p(\text{FA})$, which were used in all subsequent analyses.

Results and Discussion

Figures 5 and 6 present the ROC curves for quiet and noise conditions. The axes are in normal deviates (z scores) to allow the normal distribution, equal variance assumptions associated with the use of d' to be easily assessed. The lines are least squares fits to the data and are intended to assist in detecting reliable deviations from the expected form of normal-normal ROCs: slope ≈ 1 . Table 3 presents the slopes and standard errors for the six ROCs shown in Figures 5 and 6. With the exception of the 84 dB versus 80 dB noise condition, the best fitting straight lines had slopes that were within a standard

Table 2
Order of Stimulus and Reinforcement Conditions for Experiment 2

No.	Standard (in decibels)	Comparison (in decibels)	Noise (in decibels)	Probability	
				Standard	Comparison
1	84	60	0	1.0	1.0
2	84	60	0	0.5	1.0
3	84	60	0	1.0	0.5
4	84	60	60	1.0	1.0
5	84	60	60	0.5	1.0
6	84	60	60	1.0	0.5
7	84	70	0	1.0	1.0
8	84	70	0	0.5	1.0
9	84	70	0	1.0	0.5
10	84	70	60	1.0	1.0
11	84	70	60	0.5	1.0
12	84	70	60	1.0	0.5
13	84	80	0	1.0	1.0
14	84	80	0	0.5	1.0
15	84	80	0	1.0	0.5
16	84	80	60	1.0	1.0
17	84	80	60	0.5	1.0
18	84	80	60	1.0	0.5
19	84	60	0	1.0	1.0
20	84	60	0	0.1	1.0
21	84	60	0	1.0	0.1
22	84	60	60	1.0	1.0
23	84	60	60	0.1	1.0
24	84	60	60	1.0	0.1
25	84	70	0	1.0	1.0
26	84	70	0	0.1	1.0
27	84	70	0	1.0	0.1
28	84	70	60	1.0	1.0
29	84	70	60	0.1	1.0
30	84	70	60	1.0	0.1
31	84	80	0	1.0	1.0
32	84	80	0	0.1	1.0
33	84	80	0	1.0	0.1
34	84	80	60	1.0	1.0
35	84	80	60	0.1	1.0
36	84	80	60	1.0	0.1

Note. Probability indicates the probability of a pellet's being given for a correct trial.

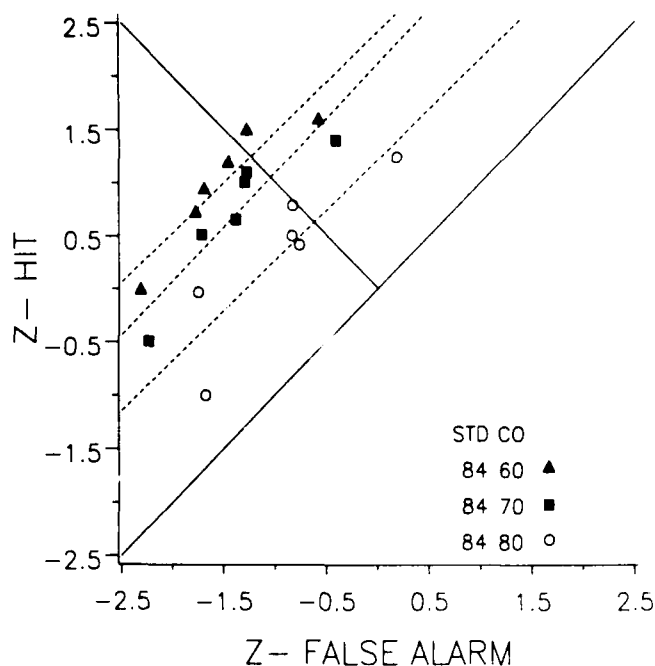


Figure 5. Receiver operating characteristic curves from Experiment 2 for the quiet condition. (Major and minor diagonals are shown, and the axes have been transformed to normal deviates. The straight lines drawn through the data points are least squares fits to the data.)

error of 1. As can be seen in Table 3, the only group with a slope reliably less than 1.0 closely approximated unit slope (0.91 ± 0.07). Because there were no apparent trends toward increasing or decreasing slopes as discriminability decreased, there is no other indication that a different distributional assumption ought to be entertained. Therefore, the normal-distribution, equal-variance assumption cannot be rejected, and it must be concluded that the d' measure provided valid point estimates of sensitivity in Experiment 1.

General Discussion

Whereas the use of discriminability data for psychophysical scaling may be relatively novel in animal research, the suggestion that a psychophysical scale could be derived in this manner dates to Fechner and the beginnings of psychophysics in 1860 (Fechner, 1860/1966). A modern, and more mathematically sophisticated, statement of Fechner's suggestion for constructing psychophysical scales from discriminability data may be found in works by Falmagne (1974, 1985). Briefly, our assumptions about the relation between discriminability and sensation may be summarized with a single functional equation (Falmagne, 1974):

$$D(a,b) = D(a',b') \text{ if and only if } \psi(a) - \psi(b) = \psi(a') - \psi(b'), \quad (8)$$

where D is a discrimination index for the stimuli a and b , and ψ is a real-valued, strictly increasing function. Two issues actually evolve from Equation 8 (Falmagne, 1974; Luce, 1959). The first issue is whether there is a solution to Equation

8 (the representation problem). This is an empirical issue to which the data of Experiment 1 and Table 4 (see later discussion) directly relate. The second issue is, what does it mean that the function ψ is a power function with an exponent of 0.35 (the interpretation problem)? This issue is more philosophical than empirical and has been the subject of much debate in psychophysics. The point of view taken by Fechner and in this article is that the function ψ provides information about the perceived magnitudes of the stimuli that are discriminated. In contrast to the Fechnerian viewpoint, other psychophysicists maintain that discriminability data bear no relation whatsoever to perceived sensory magnitudes and, therefore, cannot be used to construct psychophysical scales (e.g., Stevens, 1961, 1975, pp. 182-183). Although the broader cross-species applicability of the discrimination methods favors the Fechnerian interpretation (the direct methods favored by Stevens and his followers cannot be applied to most nonhuman subjects), it is clear that only a larger body of discrimination data than that which is currently available will indicate what is the best interpretation of Equation 8.

Within the context of the Fechnerian interpretation, the results of Experiments 1 and 2 are consistent with the conclusions drawn by Pierrel-Sorrentino and Raslear (1980) and Raslear et al. (1983) that loudness differences are discriminated, that loudness for the rat increases as a power function of sound pressure level with an exponent of 0.35, and that masked loudness is a linear function of loudness in quiet. The use of different procedures to determine and index discriminability and the determination of discriminability at a different frequency (12.5 kHz) than had been previously used extend

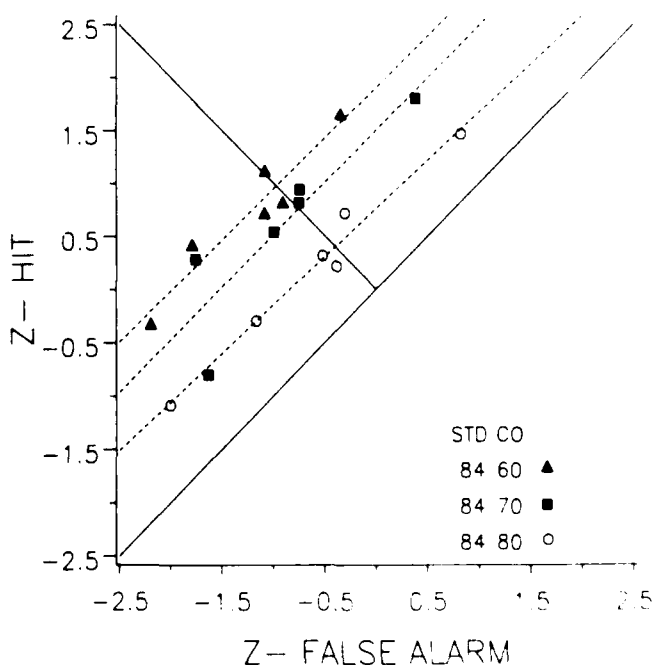


Figure 6. Receiver operating characteristic curves from Experiment 2 for the noise condition. (Major and minor diagonals are shown, and the axes have been transformed to normal deviates. The straight lines drawn through the data points are least squares fits to the data.)

the previous findings and demonstrate the broad applicability of this technique for psychophysical scaling with animals.

These results, when considered with previous reports in the literature, suggest that there may be several characteristics of loudness perception that are common across species. First, loudness is a power function of SPL. This result is commonly reported for humans (Parker & Schneider, 1980) and has now also been reported for rats (Pierrel-Sorrentino & Raslear, 1980; Raslear et al., 1983), chinchillas (Pierrel-Sorrentino & Raslear, 1980), and budgerigars (Dooling, Brown, Park, Okanoya, & Soli, 1987).

Second, perceived loudness is properly measured on an interval (rather than a ratio) scale. Unlike ratio scales, which have an absolute zero, interval scales of measurement have no fixed origin. For this reason, permissible transformations of scale (Krantz, Luce, Suppes, & Tversky, 1971) for interval scale measurement are of the form $Y = mX + b$. Ratio scales will only admit a similarity transform, $Y = mX$. It is well known that the introduction of masking noise in a loudness estimation task produces changes in both the origin (masked thresholds are generally higher than unmasked thresholds) and slope of the function (recruitment) relating loudness to SPL for humans (Lochner & Burger, 1961). Both of these effects are consistent with the rat data (Equation 7 and Figure 3 of Experiment 1; Raslear et al., 1983) and can be consistently observed in human data (Lochner & Burger, 1961; Raslear et al., 1983).

Third, when similar tasks are used, the values of n obtained for different species are more similar than not.¹ This is illustrated in Table 4, which presents values of n for seven different species on the basis of discriminability data. For birds, n ranges from 0.15 for *Melospittacus undulatus* to 0.42 for *Molothrus ater*. As can be seen from Table 4, these values span the range of values seen for the other species for which such information is available, including human and nonhuman primates. The mean value of n from Table 4 is 0.30 with a standard deviation of 0.08. Considering the differences in auditory capabilities of these species (i.e., threshold and frequency range), such convergence of perceptual function is impressive and favors the Fechnerian interpretation.

These similarities of loudness perception are based on very few observations in very few species. The cross-species investigation of these characteristics of loudness perception is now

Table 3
Regression Analysis of Receiver Operating Characteristic Curves in Experiment 2

Standard	Comparison	r^2	p	Intercept $\pm SE$	Slope $\pm SE$
In quiet					
84	60	.85	.0083	2.40 \pm 0.31	0.93 \pm 0.19
84	70	.84	.0099	2.10 \pm 0.32	1.01 \pm 0.22
84	80	.75	.0247	1.21 \pm 0.31	0.94 \pm 0.27
In noise					
84	60	.91	.0033	1.91 \pm 0.21	0.96 \pm 0.15
84	70	.79	.0184	1.50 \pm 0.29	0.99 \pm 0.26
84	80	.97	.0002	0.76 \pm 0.07	0.91 \pm 0.07

Table 4
Power Law Exponents Derived from Discrimination Data

Species	Exponent
<i>Homo sapiens</i> (Dooling, Brown, Park, Okanoya, & Soli, 1987 ^a)	0.33
<i>Homo sapiens</i> (Parker & Schneider, 1980 ^b)	0.24
<i>Macaca</i> sp. (Stebbins, 1971 ^b)	0.31
<i>Macaca fuscata</i> (Sinnott, Petersen, & Hopp, 1985 ^a)	0.28
<i>Rattus norvegicus</i> (Pierrel-Sorrentino & Raslear, 1980 ^a)	0.35
<i>Rattus norvegicus</i> (Raslear, Pierrel-Sorrentino, & Rudnick, 1983 ^a)	0.35
<i>Rattus norvegicus</i> (Hack, 1971 ^b)	0.31
<i>Chinchilla laniger</i> (Pierrel-Sorrentino & Raslear, 1980 ^a)	0.25
<i>Chinchilla laniger</i> (Saunders, Shivapuja, & Salvi, 1987 ^b)	0.22
<i>Agelaius phoeniceus</i> (Hienz, Sinnott, & Sachs, 1980 ^b)	0.42
<i>Molothrus ater</i> (Hienz, Sinnott, & Sachs, 1980 ^b)	0.42
<i>Melospittacus undulatus</i> (Dooling & Saunders, 1975 ^b)	0.15
<i>Melospittacus undulatus</i> (Dooling, Brown, Park, Okanoya, & Soli, 1987 ^a)	0.28
M	0.30
SD	0.08

^a Original exponent value reported by authors. ^b Exponent value determined by method described by Parker and Schneider (1980, pp. 399-400).

possible and must be explored. In combination with recent advances in the neurophysiology of hearing, such work will surely advance our understanding of fundamental processes in audition.

¹ The value of n typically obtained for loudness in humans using the direct methods favored by Stevens is 0.67 (Stevens, 1975). Because these methods have not been applied to nonhuman subjects, it is not known whether similar cross-species agreement also exists for magnitude estimation and production.

References

- Dooling, R. J., Brown, S. D., Park, T. J., Okanoya, K., & Soli, S. D. (1987). Perceptual organization of acoustic stimuli by budgerigars (*Melospittacus undulatus*): I. Pure tones. *Journal of Comparative Psychology*, 101, 139-149.
- Dooling, R. J., & Saunders, J. C. (1975). Auditory intensity discrimination in the parakeet (*Melospittacus undulatus*). *Journal of the Acoustical Society of America*, 58, 1308-1310.
- Egan, J. P. (1975). *Signal detection theory and ROC analysis*. New York: Academic Press.
- Falmagne, J.-C. (1974). Foundations of Fechnerian psychophysics. In D. H. Krantz, R. C. Atkinson, R. D. Luce, & P. Suppes (Eds.), *Measurement, psychophysics, and neural information processing* (pp. 121-159). San Francisco: Freeman.
- Falmagne, J.-C. (1985). *Elements of psychophysical theory*. New York: Oxford University Press.
- Fechner, G. T. (1966). *Elements of psychophysics*. (D. H. Howes & E. C. Boring, Eds.; H. E. Adler, Trans.). New York: Holt, Rinehart & Winston. (Original work published 1860)
- Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics*. New York: Wiley.

- Hack, M. H. (1971). Auditory intensity discrimination in the rat. *Journal of Comparative and Physiological Psychology*, 74, 315-318.
- Hellman, R. D., & Zwislocki, J. (1964). Loudness function of a 1000-cps tone in the presence of masking noise. *Journal of the Acoustical Society of America*, 36, 1618-1627.
- Hienz, R. D., Sinnott, J. M., & Sachs, M. B. (1980). Auditory intensity discrimination in blackbirds and pigeons. *Journal of Comparative and Physiological Psychology*, 94, 993-1002.
- Krantz, D. H., Luce, R. D., Suppes, P., & Tversky, A. (1971). *Foundations of measurement*. New York: Academic Press.
- Lochner, J. P. A., & Burger, J. F. (1961). Form of the loudness function in the presence of masking noise. *Journal of the Acoustical Society of America*, 33, 1705-1707.
- Luce, R. D. (1959). *Individual choice behavior: A theoretical analysis*. New York: Wiley.
- National Institutes of Health. (1985). *Guide for the care and use of laboratory animals* (Publication No. 86-23). Washington, DC: Government Printing Office.
- Parker, S., & Schneider, B. (1980). Loudness and loudness discrimination. *Perception & Psychophysics*, 29, 398-406.
- Pierrel, R., Sherman, J. G., Blue, S., & Hegge, F. (1970). Auditory discrimination: A three variable analysis. *Journal of the Experimental Analysis of Behavior*, 13, 17-35.
- Pierrel-Sorrentino, R., & Raslear, T. G. (1980). Loudness scaling in rats and chinchillas. *Journal of Comparative and Physiological Psychology*, 94, 757-766.
- Raslear, T. G., Pierrel-Sorrentino, R., & Brissey, C. (1975). Concurrent assessment of schedule and intensity control across successive discriminations. *Journal of the Experimental Analysis of Behavior*, 23, 247-254.
- Raslear, T. G., Pierrel-Sorrentino, R., & Rudnick, F. (1983). Loudness scaling and masking in rats. *Behavioral Neuroscience*, 97, 392-398.
- SAS Institute. (1985). *SAS user's guide: Statistics* (Version 5). Cary, NC: Author.
- Saunders, S. S., Shivapuja, G. B., & Salvi, R. J. (1987). Auditory intensity discrimination in the chinchilla. *Journal of the Acoustic Society of America*, 82, 1604-1607.
- Sinnott, J. M., Petersen, M. R., & Hopp, S. L. (1985). Frequency and intensity discrimination in humans and monkeys. *Journal of the Acoustical Society of America*, 78, 1977-1985.
- Stebbins, W. C. (1971). Hearing. In A. M. Schrier & F. Stollnitz (Eds.), *Behavior of nonhuman primates* (Vol. 3, pp. 159-192). New York: Academic Press.
- Stevens, S. S. (1961). To honor Fechner and repeal his law. *Science*, 133, 80-86.
- Stevens, S. S. (1975). *Psychophysics*. New York: Wiley.

Received May 10, 1988

Revision received January 11, 1989

Accepted January 13, 1989 ■